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SEARCHING FOR EXTRAGALACTIC PLANETS

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Abstract

Are there other planetary systems in our Universe? Indirect evidence has been found for planets orbiting other stars in our galaxy: the gravity of orbiting planets makes the star wobble, and the resulting periodic Doppler shifts have been detected for about a dozen stars [1]. But are there planets in other galaxies, millions of light years away? Here we suggest a method to search for extragalactic planetary systems: gravitational microlensing of unresolved stars. This technique may allow us to discover planets in elliptical galaxies, known to be far older than our own Milky Way, with broad implications for life in the Universe.

The phenomenon of gravitational microlensing is as follows. A massive object, be it a black hole, planet, star, etc., passes very near to the line of sight to a star being monitored. The gravity of the massive object bends the starlight (gravitational lensing), producing multiple images of, and magnifying, the monitored star for a short time. The multiple images can not be resolved (hence the prefix micro), but the amplification of the light intensity can be detected. The amplification has a well-defined characteristic temporal behaviour, allowing such events to be distinguished from other possible intensity changes such as those due to variable stars [2].

In the case where the lens itself is a binary object, the microlensing lightcurve can be strongly affected, exhibiting short periods of very large magnification, coming in pairs [3, 4]. Gravitational lensing events of this type involving binary stars have been observed by the MACHO and EROS teams in programmes monitoring several millions of stars [5]. The short duration large magnification events are referred to as caustic crossings. The magnification along these caustic curves is formally infinite, and in practice quite large, in excess of ten. Caustics are well known in optics, and can be seen, for example, as the oscillating patterns of bright lines on the bottom of a swimming pool.

The utility of such events in searching for planetary systems is clear: a solar system can be described to first approximation as a binary object, as is the case of our own solar system, consisting primarily (in mass) of the Sun and the planet Jupiter. In Figure 1, we show two example lightcurves of microlensing events, together with the trajectories of the source stars relative to the caustic curves. In both cases the star has a companion one one-thousandth as massive, like the Sun–Jupiter system.

Previous work has shown that planets might be detected in microlensing events in the bulge of the Milky Way galaxy, or in the Small and Large Magellanic Clouds, which are small galaxies in orbit around the Milky Way [4]. Stars in the bulge and in the Magellanic clouds can be resolved easily, and surveys routinely monitor of order ten million stars for microlensing events. Evidence for a planet orbiting a binary star system in the Milky Way bulge has recently been presented in a joint publication of the MPS and GMAN collaborations [6].

In order to observe planetary systems in more distant galaxies, we must resort to a technique known as pixel microlensing [7]. Individual stars in distant galaxies can not be resolved, but this does not invalidate the method. Each pixel of a telescope camera collects light from a number of stars in the distant galaxy. If a single star is magnified due to gravitational microlensing, the pixel will collect more light. Of course, the light from other stars on the pixel makes a magnification more difficult to observe, but the technique works in practice [8].

The pixel microlensing surveys that have been undertaken observe the Andromeda Galaxy (M31), the nearest large galaxy to the Milky Way. These surveys have used ground based telescopes. The bulge of M31 is quite dense, which allows a high probability of microlensing events. We have calculated the rate of planetary events observing M31 with a telescope like the Canada-France-Hawaii telescope (CFHT) on Mauna Kea [9]. We assume that every star has a companion that is one one-thousandth as massive, just like the Sun and Jupiter. Furthermore, we assume, as is true for known binary stars, that the distribution of orbital periods is such that ten percent of such systems lie in each decade of period, from a third of a day to ten million years. This gives a 10% probability that a star has a companion between one and five AU (Astronomical Unit, the distance between the Earth and the Sun), in rough agreement with the observational findings of Marcy et al. [1]. With a long–term monitoring program observing every night for the five months that M31 is visible in Hawaii over a period of eight years, we expect to observe about one planetary event.

To increase the chances to detect planetary systems in distant galaxies, we require a space telescope such as the proposed Next Generation Space Telescope, to be launched around 2007. This will be a large (about 8 metres in diameter) infrared telescope at a Lagrange point

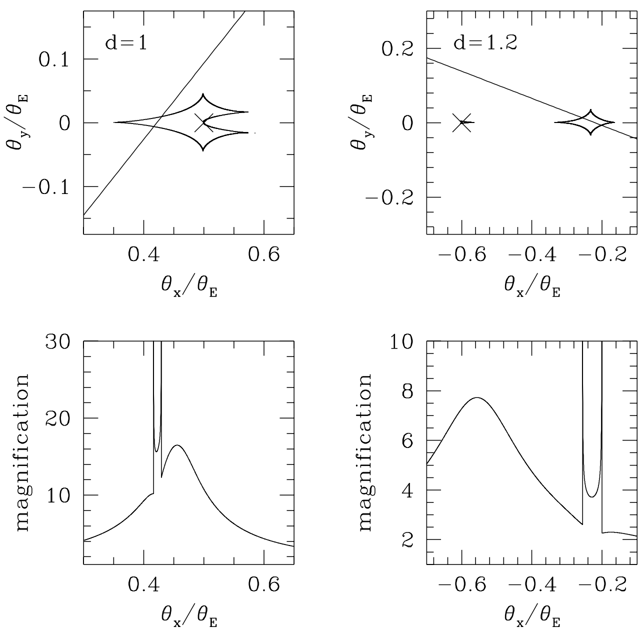

Figure 1: Microlensing events due to a planetary system. We illustrate the trajectory of a source star over the caustic curves of a lens star and its planet. We then illustrate the observed magnification of the source star along its trajectory. The cross indicates the star's position, whereas the planet lies off the plots at −0.5 and 0.6, respectively. The plots are in units of the Einstein angle θ_E, which is the characteristic angular scale of a microlensing event. Also shown is the star–planet separation d in units of θ_E.

of the Earth–Moon system, and it will be more than ten times as sensitive as the Hubble Space Telescope.

We have calculated the rate of events we might detect with the NGST observing the giant elliptical galaxy M87 in the Virgo cluster, at a distance of fifty million light–years. With the same assumptions as the M31 calculation, we find that an NGST survey of two month's duration, taking one image each day, should be able to detect of order three planetary systems. We find that such a survey is most sensitive to events where the separation between caustic crossings is about five days. An alert system for microlensing events would allow more frequent measurements of the light curve during the caustic crossings, with the possibility of determining the orbital parameters of the planetary system.

We now make some comments about the dependence of the observed rate of microlensing events on the various physical parameters. As long as the size of the observed galaxy is small compared to the distance to it, the fundamental rate of events is constant. However, a more distant galaxy will appear smaller, with more stars per pixel, which decreases the rates. On the other hand, if the galaxy is too close, many images must be taken in order to monitor enough stars, requiring more telescope resources. For the pixel scale of the NGST, M87 is at a fairly optimal distance.

We have shown that pixel microlensing may be used to detect extragalactic planetary systems. This is the most promising available technique for discovering planets outside our own galaxy. This is especially interesting in that we might find planets in elliptical galaxies such as M87, known to contain considerably less heavy elements than our own spiral galaxy. The discovery of an extragalactic planet in a galaxy very different from ours would have broad implications for the origin of life in the Universe.

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